

## **Continued Development of the Look-up-table (LUT) Methodology For Interpretation of Remotely Sensed Ocean Color Data**

W. Paul Bissett  
Florida Environmental Research Institute  
PO Box 292397  
Tampa, FL 33687 USA  
phone: (800) 928-6402 x102    fax: (800) 928-6402    email: [pbissett@feriweb.org](mailto:pbissett@feriweb.org)

Award Number: N000140610370  
<http://www.FERIweb.org>  
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### **LONG-TERM GOAL**

The overall goal of this work is to refine and validate a spectrum-matching and look-up-table (LUT) technique for rapidly and accurately inverting remotely sensed hyperspectral reflectances to extract environmental information such as water-column optical properties, bathymetry, and bottom classification.

### **OBJECTIVES**

My colleagues and I are developing and evaluating new techniques for the extraction of environmental information including water-column inherent optical properties (IOPs), shallow-water bathymetry, and bottom classification from remotely-sensed hyperspectral ocean-color spectra. We address the need for rapid, automated interpretation of hyperspectral imagery. The research issues center on development and evaluation of spectrum-matching algorithms, including the generation of confidence metrics for the retrieved information. Dr. Curtis D. Mobley at Sequoia Scientific, Inc., is leading this effort and he is the author of this report.

### **APPROACH**

The LUT methodology is based on a spectrum-matching and look-up-table approach in which the measured remote-sensing reflectance spectrum  $R_{rs}$  is compared with a large database of spectra corresponding to known water, bottom, and external environmental conditions. The water and bottom conditions of the water body where the spectrum was measured are then taken to be the same as the conditions corresponding to the database spectrum that most closely matches (by some chosen metric) the measured spectrum.

In previous LUT work (Mobley et al., 2005; Mobley and Lesser, 2007), we have simultaneously retrieved water column IOPs, bottom depth, and bottom classification at each pixel from image remote-sensing reflectance spectra. Although this is much to ask from a simple  $R_{rs}$  spectrum, we have shown that all of this information is uniquely contained in hyperspectral reflectance signatures and that the information can be extracted with considerable accuracy.

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## WORK COMPLETED

In previous work (e.g., Mobley, et al., 2005; Lesser and Mobley, 2007) we evaluated numerous options for applying the basic LUT algorithms. These options include matching the closest  $k$   $R_{rs}$  spectra, rather than just the closest one ( $k = 1$ ), spectral and spatial smoothing of image spectra before processing, and spatial smoothing of retrieved values after processing, and different spectrum-matching metrics for determining the “closest” match. We have also quantified the errors in the LUT  $R_{rs}$  database generation associated with the use of unpolarized (scalar) radiative transfer calculations (using a special version of HydroLight), compared to exact (but very time consuming) calculations that included polarization (You et al., 2009). This previous work mostly used PHILLS imagery from the Lee Stocking Island, Bahamas area acquired during the ONR-sponsored CoBOP (Coastal Benthic Optical Properties) program.

This year’s work centered on retrievals using CASI airborne imagery from Australian waters, which was made available by A. Dekker at CSIRO Land and Water, Canberra and S. Phinn at the University of Queensland. Those waters have different inherent optical properties and bottom types than the Bahamas, and thus provide additional tests of the LUT methodology.

A. Dekker and S. Phinn organized an algorithm comparison workshop in Brisbane, Australia, during which LUT and several other retrieval algorithms were compared via application to a common set of images. This comparison required preparing for and attending pre-workshop meetings in Florida and Italy, processing the common imagery from Bahamas and Australian waters, developing software for presenting retrieval outputs on a common format, participating in the Brisbane workshop, and writing sections of the resulting paper (Phinn et al., 2009).

## RESULTS

One of the Australian images from Moreton Bay, Queensland provided an instructive test of the LUT methodology. Before processing this image, a new LUT  $R_{rs}$  database was created using a wide range of absorption and backscatter spectra that were presumably characteristic of the ranges of the IOPs that might be found in Moreton Bay. (These IOPs are much different than any previously studied waters, so previously created databases were not expected to give good retrievals.) In creating the initial database, it was assumed that absorption and backscatter were correlated, i.e., low (high) absorption was matched to low (high) backscatter. The associated LUT depth retrievals were good in areas less than about 3 m deep. However, retrievals in a channel with depths greater than 10 m were not more than 3 to 4 m, which was much too shallow.

Examination of the closest-matching image and LUT database spectra showed that the best matches were good in shallow areas, where  $R_{rs}$  is dominated by bottom reflectance and water IOPs are relatively unimportant. However, in the deeper channel, the closest matches, hence the depth retrievals, were very poor. The poor  $R_{rs}$  matches in deep water implied that the initial database did not have IOPs representative of the waters being imaged. The original LUT database was then expanded by allowing IOP combinations in which each low to moderate absorption spectrum could occur along with a range of low to moderate backscatter values. The absorption and backscatter spectra were then uncorrelated in magnitude. When the image was reprocessed using the expanded database, the channel retrievals were better.

Figure 1 shows the retrieved vs. acoustic depths for the initial (database1) and expanded (database 2) LUT  $R_{rs}$  databases. Note that the database 1 retrievals level off at 3 to 4 m, no matter how deep the water is. The database 2 retrievals are much better down to about 10 m, but are still very poor for depths greater than 10 m, indicating that the  $R_{rs}$  database is still somewhat inadequate (assuming that the CASI radiometric calibration and atmospheric correction were good). Figure 2 shows the Moreton Bay image area with the pixel-by-pixel depth retrievals binned for convenient display. The white squares in those images show the locations of the acoustic pings used for ground truth in Fig. 1. In Fig. 2, note that the shallow areas are much the same, but that the channel in the middle of the image has deeper retrievals for database 2.

The important lesson learned from this image is that poor retrievals will be obtained if the  $R_{rs}$  database does not contain IOPs and bottom reflectances that are characteristic of the environment being imaged. In the case of Moreton Bay, the absorption and backscatter IOPs were not well correlated. This had not been the case in Bahamas waters, in which low (high) absorption was associated with low (high) scattering. Thus, when creating LUT  $R_{rs}$  databases, it is important not to build in assumptions about IOP (or other) correlations, unless ancillary data are available to support those assumptions.

## **IMPACT/APPLICATION**

The problem of extracting environmental information from remotely sensed ocean color spectra is fundamental to a wide range of Navy needs as well as to basic science and ecosystem monitoring and management problems. Extraction of bathymetry and bottom classification is especially valuable for planning military operations in denied access areas.

## **TRANSITIONS**

Various databases of water IOPs, bottom reflectances, and the corresponding  $R_{rs}$  spectra, along with the specialized HydroLight code and spectrum-matching algorithms have been transitioned to WeoGeo, Inc. for processing his extensive collection of SAMSON imagery acquired in coastal California and Florida waters, and for use in comparisons of LUT and LIDAR bathymetry. Code for display of retrieval results has been given to S. Phinn and colleagues at the Univ. of Queensland, Australia. The LUT algorithms, spectrum matching code, and selected databases are now being transitioned to the Naval Oceanographic Office under contract N0001409C0553.

## **RELATED PROJECTS**

This work is being conducted in conjunction with Curtis Mobley at Sequoia Scientific, Inc., who is separately funded for this collaboration. The international algorithm comparison study involves collaborators from several countries, who are funded from other sources.

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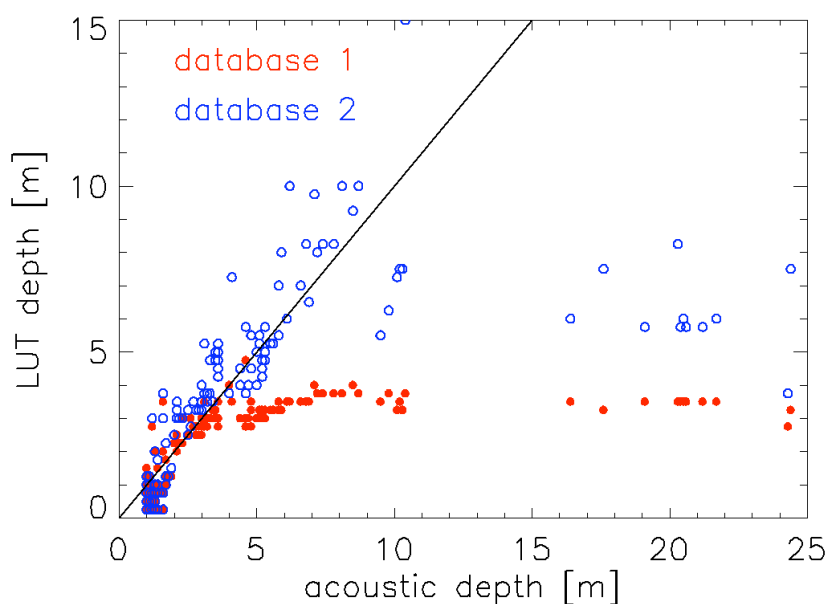
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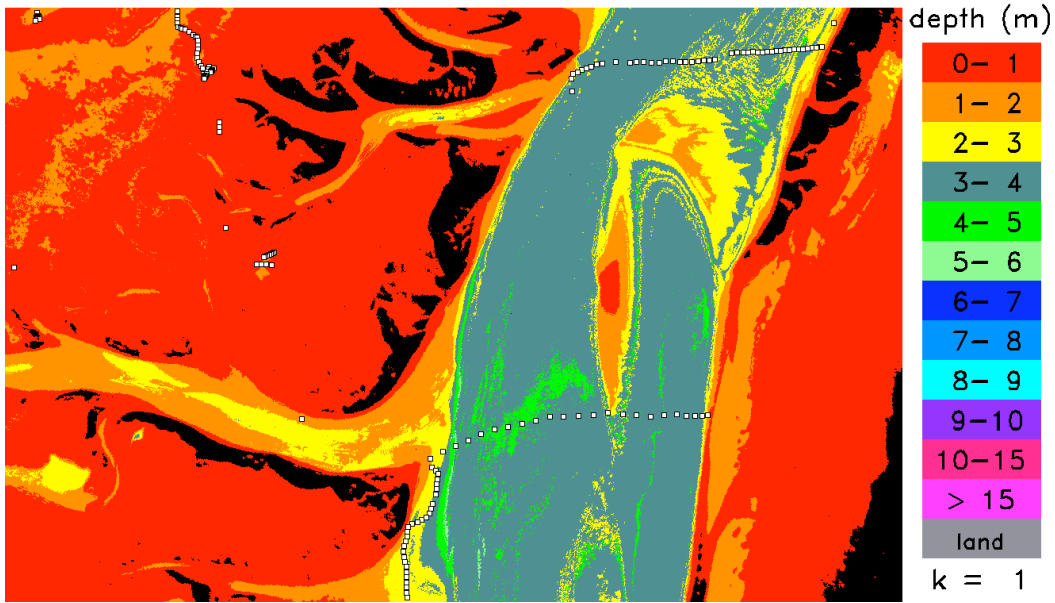
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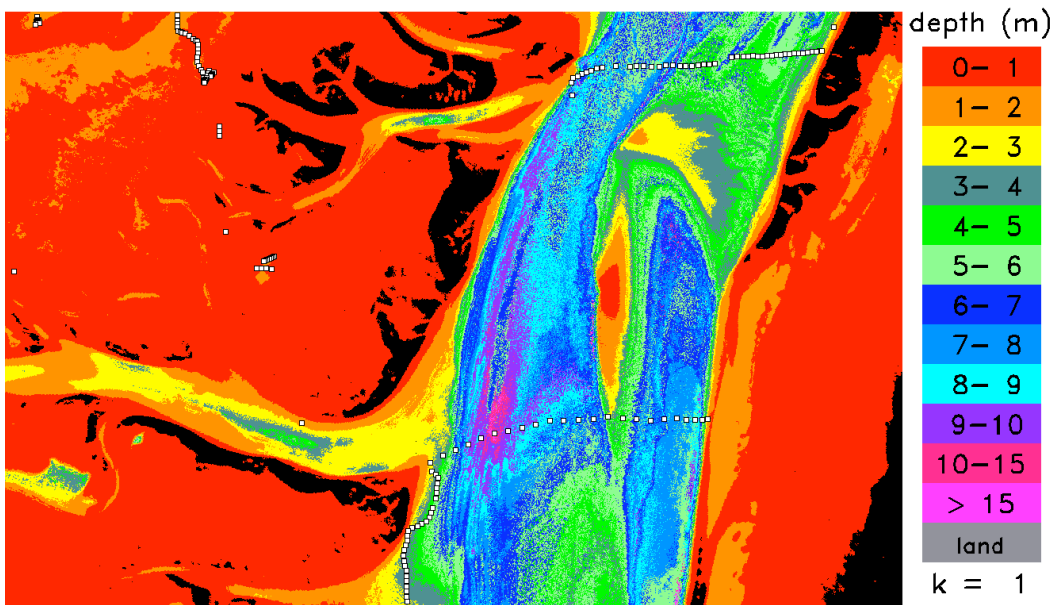


**Fig. 1. LUT depth retrievals for the Moreton Bay image for the original database 1 and for the expanded database 2. [Figure shows retrieved vs. acoustic depth, color coded according to which database was used.]**

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file: C:\LUT\Algo-comp\Moreton\_Bay\imagery\040729a\_RainbowCh\_R0\_LUT\_24Aug\_repRrsv2\_10NN.bil



**Fig. 2.** Depths for the Moreton Bay image as retrieved using the original LUT database 1, top, and expanded database 2, bottom. Note that the shallow areas are much the same, but that the channel depths are deeper in the bottom image. Masked land areas are black. White squares are the locations where acoustic bathymetry is available for ground truth. [Figure shows the LUT-retrieved depth at each image pixel for the Moreton bay image, color coded by 1 m depth bins.]